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Chapter

Mechanical and Electrical Design Calculations of Hybrid Vehicles

Khalid G. Mohammed

Abstract

Electric power is widely used in electric traction for many reasons: it is easy to control the speed of an electric motor, the absence of exhaust gases, free of noise, it has high starting torque, and it needs less maintenance than its mechanical counterpart. In the current research, a modern hybrid car is designed and manufactured in three ways. The first method is using a 220 volt AC electric power to charge five series batteries; each battery has 12 VDC (35 A/h) to supply totally 60 VDC input voltage for the electronic inverter which converts 60 VDC to 60 VAC (three-phase voltage) as a controllable voltage source to three-phase synchronous motor (SM) type (BLDC-YG1-ZZ-1200 W). The second method is to take advantage of the solar energy which is almost available in Iraq environment throughout the year to be stored in the batteries, especially during the shutdown of the machine and when it stops it under the sun. The solar panel is fixed on the vehicle's roof; it has a power of 100 watts. The third method is the mechanical energy by using the bicycle pedal to move the wheels of the car; it is useful in the event of a sudden interruption of electrical power or a technical failure in the vehicle. In addition, three kinds of electronic devices are used for control. The first control is electric battery charger. The second control is to convert solar radiation into electrical energy to be stored in the batteries. The third control is to regulate the accessories of another electric vehicle. The vehicle was tested in the province of Diyala, Baquba, Iraq, on a flat and tilted land (Al Mafraq Bridge, Baquba city). The steady-state speed reached more than 40 km/h with a total load of more than 125 kg. The design is subjected to real electrical and mechanical engineering tests alongside using decades of applied equations on locomotives and electric vehicles to validate the experimental tests.

Keywords: hybrid vehicle, electrical, solar and mechanical energies

1. Introduction

Electric cars as many people have seen have acquired a great significance because it is an alternative future way for transmission due their features. In spite of that, there are three difficulties that face the evaluation of the electric cars: long time of charging, cost of batteries, and limited driving ranges [1–3]. The great developments in power electronic inverters which are used as a main controller inside the electric cars have given a step frontward [4, 5]. In addition to that, the electric machine motors such as DC motors, induction motors, and three-phase synchronous motors have witnessed effective process in material and electromagnets aided to increase their efficiency [6–8].

The traction motors need strongly two important parameters to recognize their performance: high starting torque and acceleration. Furthermore, the traction motor should have the initial force to overcome the resistance force induced at the starting movement [9, 10].

The electric car was first invented in the USA and Scotland in 1834. After that, slow progress began to prove its importance until three eras of development to this day. These three boom eras were dominated by factors such as the presence of oil, prices, and crises, and the second factor is the pollution of the environment and the increase in temperature of the earth.

The first boom era began in 1850 and continued to 1900 in the USA where the DC motors were the basic component of the drag with the presence of batteries. The second boom era started from 1950 to 2000, where the 1973 oil crisis, pollution of the environment, and global warming contributed to this development. The third boom started since the beginning of 2000 to the present day, where the Japanese companies, Toyota and Nissan, and the German company, Mercedes or BMW, and Chinese companies as well as US companies entered in a fierce competition to control the global markets [11, 12]. **Table 1** shows the history of the electric car since 1834 until these days.

Name	Year and country	Type of traction	Notes
Thomas Davenport	1834, USA	DC motor	
Robert Anderson	1832–1839, Scotland	First prototype electric-powered carriage	
Andreas Flocken	1888, Germany	The first four-wheeled electric car	
Pope Manufacturing Co.	1897, USA	The first commercial electric vehicle	
La Jamais Contente	1899, France	The first electric vehicle to travel over 100 km per hour	
	1900, USA	Electricity-powered cars	Capturing 28% of the market
The petrol-powered Ford Model	1908, USA	Electric car Model T	
A Baker Electric	1909, USA	Automobile	
Charles Kettering	1912, USA	The electric starter was invented instead of hand-crank	
Global EV stock	1912, USA		Market, 30,000
Carmaker Tama	1947, Japan	Electric car with a 40 V lead acid battery	
General Motors	1996, USA	EV1 electric car	
Toyota	1997, Japan	The Prius, the world's first commercial hybrid car	
BEV Nissan	2010, Japan	The world's largest electric car sharing service	
Nissan LEAF	2011, Japan	New car models	
PHEV Chevrolet Volt	2012, USA	New car models	

Table 1.
Electric car history [12].

1.1 Electric traction motors

1.1.1 Traction motor types

There are three types of electric motors which are nominated to use: DC motor, AC single- or three-phase induction motor (IM), and three-phase synchronous motor (SM). These motor features are chosen depending on the nature of voltage-supplied source, performance, and method of construction.

1.1.1.1 DC motors

DC motors are characterized as follows: exacted spin speeds, the same wide range of changing speed with the possibility of easy control, the possibility of reversing the rotational movement, and the possibility to start an appropriate torque.

1.1.1.2 Induction motors

There are two types of induction motors: the first type has a rotor shape-like squirrel cage arrangement. It is characterized by simple installation, low cost, and hardness. This type is suitable for applications requiring constant rotation speed. The second type is called the slip-ring motor which has a wound rotor with a three-phase winding. The first three terminals of the windings are shorted, while the second three ending terminals of the windings are connected to the three slip rings. Slip-ring induction motor is suitable for applications that need great starting torque for a few seconds with a decrease in the value of the starting current. This type is characterized by the first type with its great ability to control the speed and torque and the starting current by using additional variable three-phase resistance connected through the three slip rings of the motor.

1.1.1.3 Synchronous motors

This type of motor is suitable for applications that need a constant rotation speed value and great power in addition to the possibility designed to operate at slow speeds by a high power factor and high operating efficiency.

1.2 General characteristics of traction motors

The general electrical mechanical properties required for the traction motors are:

1. A large starting torque and acceleration which are needed by electric vehicle to overcome the power large traction required at starting the movement. In addition to the traction force needed to overcome the resistance to train traffic, also, the movement toward the highest inclined land means the need to extra drag to overcome the effect of gravity.

2. Series motor properties: It is necessary for the motor used in the vehicle to have series motor properties between motor speed and torque, for the following reasons:

    - Operating more than one motor per electric vehicle: Electric vehicle usually contains several similar traction motors which are installed with movement gears and wheels. As long as the wheels of movement have the same diameter, the motor speeds are equal, and the entire load is equally distributed between the motors. But because of unequal corrosion that happens, there is a dissimilarity in the wheels' diameters. This may cause an unequal distribution of the load between the motors.

- Self-protection feature: Because of the characteristics between the speed and torque, the speed of the motor decreases as the torque increases. This relationship is correct when neglecting magnetic saturation.

- Lower power consumption during load increase: During load increase, the required traction increases, as is the case with a sloping level, when the required power by the series motor is much lower than the power calculated by the parallel motor; the reasons are mentioned above.

1.3 Advantages and disadvantages of electric traction

The most important advantages of using the electric motors in traction are anti-contamination that accompanies with the use of electric motors. The electric motor provides a great starting torque, which allows high acceleration value at the start of the vehicle. So, they allow carrying twice as many people on the same way because of the high flow of vehicle speed. The electric motor provides a soft change in the ultrafast speed.

The electric motor provides the possibility of using the electric brake, which enables the return power to the electric grid when using the brake regeneration while walking down the slopes. The use of electric brakes leads to savings in the use of the mechanical brakes which prolongs life and reduces corrosion in the roller wheels and iron bars. The time required for the maintenance and repair of an electric vehicle is lesser than the need by others. The maintenance and repair of the electric vehicle cost about half of those cost in other vehicles. They did not need electric vehicles to the time to become operational. Finally, getting rid of the exhaust fumes, which may contain toxic elements, is considered one of the most important advantages of electric traction, especially in hypocrisy and roads under the ground. The disadvantages of electric traction are as follows: The cost of construction is high, any malfunction in the electrical grid even for a brief period will lead to total paralysis in traffic and might extend long hours, and also an overlap occurs between the electric traction network and communication signals.

1.4 Feeding electric traction system networks

There are three different types of feed electric traction systems:

a. DC voltage system (DC power system)

b. Single-phase AC voltage system

c. Three-phase AC voltage system

(a) DC power system: DC voltage of 600 to 700 V is used globally for trams in the cities, while the ongoing effort of the 1500–3000 V is used outside the cities. The iron bars represent the neutral line. The specification states that the voltage drop should not be more than 7 volts between any two points on the neutral line (iron bars).

As for the electric bus (trolleybus), the two electric lines should be two overhanged, the feeding line and neutral line. The voltage must not exceed 10% plus or minus. The DC network is fed into electric power stations 3–5 kilometers away from each other inside the cities and 40–50 kilometers outside the cities. Electric power stations are also supplied with power from the AC voltage networks of 110–122 kV, where it is converted into a DC voltage required.

(b) Single-phase AC system: This system uses a voltage of 11–15 kV (2/3 16) or 25 Hz. If power plants are used to feed traction stations, there will be no difficulty in generating the required voltage and frequency. In the case of high-voltage networks at 50 or 60 Hz frequency, the frequency limit should be reduced to the desired limit (a three-phase synchronous motor is used to operate a single-phase generator to generate the required voltage and frequency).

In this case, the traction network consists of a single overhanged line, and the rails represent the neutral. The traction line carries the transformer to reduce the voltage to 300 or 400 volts to feed the general series motor, and the motor speed can be controlled by changing the voltage of the transformer.

Low frequency (16.667) or 25 Hz is used to improve the efficiency and power factor of the motor. It also helps to reduce the electrical spark between the brushes and the commutator, in addition to reducing the induction impedance of the traction network transmission lines and thus reducing the lost voltage. This increases the distance between feeding stations to 50–80 kilometers. Low-frequency use also helps reduce interference with telephone and communication networks.

(c) Three-phase AC system: Three-phase induction motors are used as drive motors in this case with a voltage of 3.3 kV and a frequency of 16.667 Hz. The power stations receive power from high-voltage networks, and the voltage and frequency are reduced to the required limit. The traction network consists of two transmission lines; the line bar is the third line. The advantages mentioned, due to the use of low frequency, can also be mentioned in this system.

1.5 A factor that must be considered when choosing an electric motor

Choosing an electric motor depends on the circumstances that will work underneath and the type of load. There are several factors to consider when choosing an electric motor to suit industrial applications, and one of the most important are as follows:

1. Electrical properties:

    a. The properties of the start of the movement, in terms of the value of each of the torque and the drawn current

    b. The properties of the motor during operation, the relationship between the torque and speed, and the relationship between speed and power, current, losses, and efficiency

    c. The extent of control the speed of rotation during operation

    d. How to turn off the motor and break it

2. Mechanical considerations:

    a. The type of outside cover of the motor, the type of cooling of the motor.

    b. The type of rotary bearings used.

c. What is the transmission way between the motor and the load.

d. The noise level, which is produced by the motor.

3. The motor size and the design power:

a. Loading requirements in terms of continuous or short term or intermittent

b. Ability of the motor to deal with excessive loads

4. The cost of the motor:

a. In terms of the primary and operating cost

In addition to the previous factors, it should be kept in mind the current user type, in terms of being a DC constant, AC single-phase, or three-phase current. From the above it is clear that there are many factors must be considered when choosing a motor to drive a given load, and despite the fact that the cost of the machine came in the last previous mechanical considerations, but the final decision in the selection of the machine, depending upon significantly. The desired and selected machine must meet all the technical requirements of the load and at the same time should not be so high till it succeeds economically. In fact, the choice of the motor requires careful study and analysis of its characteristics and load together.

In addition to the full knowledge of the entire system of stirring and control devices, it is required to have switching devices and change the frequency.

The latest factors and their impact on different types of motors will be discussed in detail separately in the next section, to illustrate the impact of each of them:

1. Electrical properties:

The properties of the different motors in terms of operating properties and the properties of the start of the movement and speed control have been studied in the decisions of the DC machines and AC small power motors.

2. Mechanical considerations:

A. Cover user type: The main objective of the outer frame of the machine is not only to provide protection for the people and the workers but also to provide protection for the machine itself, against moisture, dirt, dust, and unwanted objects and what might leak out of the motor fumes and flammable materials. There are different types of the motors according to their protection ways:

i. Open type

ii. Mesh cover-protected type

iii. Type covered against scattering of liquids and dust

iv. Water- and rain-protected type

v. Self-air cooling

vi. Separated cooling

vii. Tubed cooling

B. Bearings used type:

There are two types of bearings used in electric motors, namely, ball bearings and roller bearings.

i. Ball bearings: used in motors up to 100 horsepower. They are preferred by other types due to its many benefits. The most important of these are little friction losses, less maintenance, and longer durability than the other wheels. Between stator and rotor. But its main disadvantages are its high cost and noise, especially at high speeds.

ii. Roller bearings: used in motors that work in quiet places such as hospitals, offices, and classrooms.

C. Types of transmission: Transfer the generated mechanical power to the machine to drive the mechanical load axis; there are many ways to lead the load, and the most important are:

i. Direct transmission: The load and the motor are directly connected by a mechanical coupling which is solid or flexible. Coupling is used when the load speed is equal to the speed of the motor.

ii. Driving by timing belts to transfer power of up to two hundred and fifty kilowatts, preferably when using this method to be less distance between the axis of rollers equal to four to five times the diameter of the largest pulley, and so that the maximum ratio between the diagonal rollers are 1: 6, as there is in this case sliding between the borders of three to four percent. The disadvantage of this method is that it requires a large space, so the belts make tension sideways on the bearings, causing increased friction missing out and fatigue.

iii. Driving by using V-type belts: This type of V-type conveyor is used between two rollers with the same shape. This method is used to transport large valves that exceed the capacity of the belt, and it operates with a small slip that can be neglected.

iv. By driving chains: This method is more efficient and is used at high speeds, but the cost is the biggest. But they need less space than the previous two, where the required distance between the axis of rollers is of one and half to twice the diameter of a larger pulley. It is used in wet and dust places so that the chains should be protected by its own cover, as it should have perfectly parallel axes, to avoid lateral tensile axis rollers.

v. By steering with gearbox: This method is used when the motor used has a high speed to drive a load when its speed is slow; the motor is built and merged with gearbox by the required speed ratio.

D. The noise produced by the motor: noise produced inside the motor for the following reasons:

   i. Alternating magnetic field inside the motor caused by vibrations in the iron body segments and the motor

   ii. The movement of air within the instrument

   iii. Friction in the bearings

Noise level should be reduced to the lowest level possible, especially in motors that are used in hospitals, offices, theaters, and classrooms. To reduce the transitional noise from the motor to the other places, it must be installed with rubber or helical springs to absorb vibrations.

3. Size of the motor and its power:

The factors that control the size and capacity of the motor is the maximum temperature reached by the motor during the service run under load conditions, in that it continuously or intermittently, or short-term and the maximum. It has been found that the motor that achieves the first condition of temperature also achieves the second condition of the torque required. It is worth mentioning here that the maximum temperature of the motor is designed on the basis of the type of the insulating material used. Motor insulations are classified to types depending on the maximum temperature allowed.

Loading requirements in terms of that continuous or short term or intermittent: usually electric motors are designed based on the amount of time in which they operate the machine required load as well as the amount of time in which the machine is stationary for work or runs at no load. On this basis, the rules that follow to choose electric motors indicate the possibility of rating motor in terms of time plan. Here are some operating types of motor:

A. Continuous operation: the machine working needs to do its job in this case to start the motor full rating and on continuous so as to reach the temperature in all parts of the motor to the maximum amount at which the motor has been designed on the basis of not beyond it with the operating continuation of any period after that.

B. Short-term operating: The machine working in this type of operation runs sporadic periods, each of which extends over a specific period of time, the measured temperature so as not to exceed in all parts of the motor the maximum temperature.

2. Methodology: design of vehicle

The required torque for moving vehicle gear box assembly is subjected to many rules. These rules are interrelated with tires, friction, wind resistance, weight, and tilt level [4].

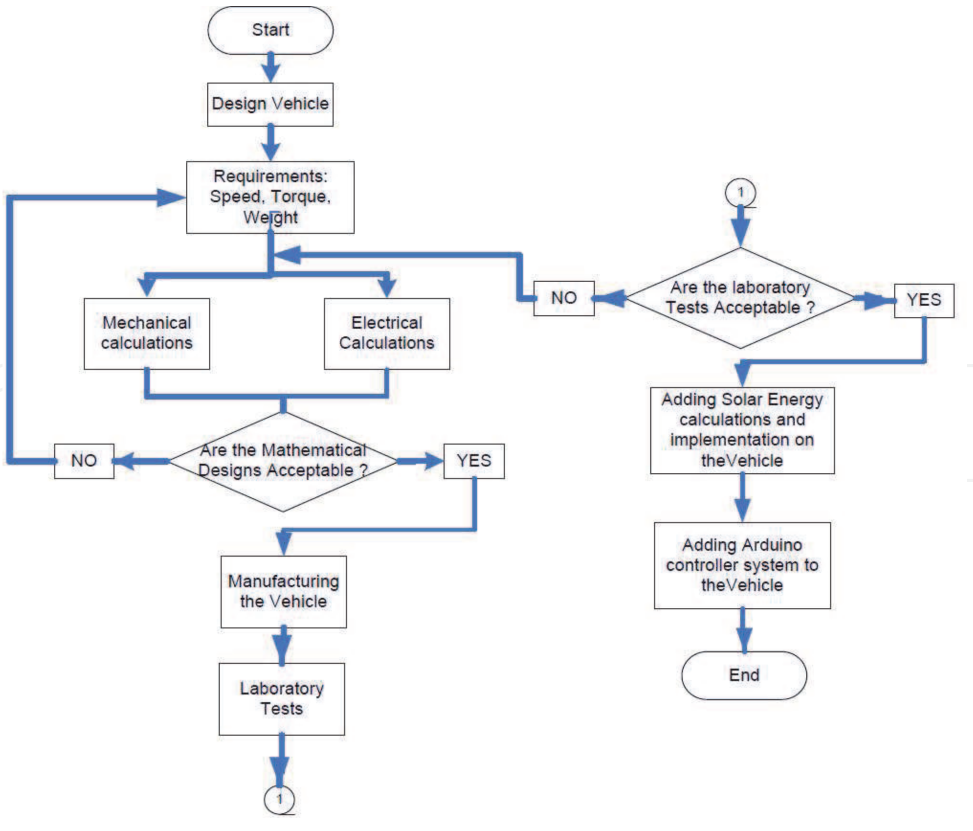

Figure 1.
Flowchart of the vehicle design.

A tire subjected to a load will be deformed and flattened until the contact area with the ground will get a force equal to the load on the same wheel. When the tire rolls, the resulting force at contact is not centered but placed at a distance: this is the lever arm required to calculate the required torque on the tire to overcome the resistance by rolling (it is not the tire radius). The friction coefficient between the tire rubber and ground is only required to find out the maximum torque before sliding. This may occur in case of a very high starting torque when the moment of vehicle inertia has an essential role. Tire deformation demands energy, and tires have an internal friction in which it is clear that after driving, tires heat up. The motor must supply the torque and energy to overcome all losses. If, for instance, two wheels are active, the rolling resistance and other losses are present on all four wheels even if the torque is applied only on two. Since rolling resistances are not linear, their sum should consider load distribution on the different axes and wheels. All before is valid for a flat horizontal ground. When the road is inclined with an angle, then the e = weight force can be analyzed to components. The downward component is F = G × sin (angle). The friction coefficient also adds an opposite torque to the tire torque. **Figure 1** explains the design flowchart of the vehicle.

2.1 Mechanical model

The required traction force on the tire of the vehicle is F_t. The force F_t induced on the edge of the vehicle tires is to move it itself. The force traction required for the vehicle on the ground level is shown by Eq. (1):

$$F_t = F_a + F_r \tag{1}$$

If the vehicle is moving at an inclined level, it can be expressed by Eq. (2):

$$F_t = F_a + F_r + F_g \tag{2}$$

The force needed for the linear acceleration of the vehicle is F_a. The required force to overcome the resistance to vehicle traffic is F_r. The power required to overcome the effect of gravity is F_g. The positive signal is used when the vehicle goes up to the sloped level, while the negative signal is used if the vehicle drops to the skewed level.

2.2 Calculating the needed force for acceleration

The effect of force motion F_a on a vehicle mass of m kg and its weight W and the value of the vehicle linear acceleration generated are calculated by Eq. (3):

$$F_a = mw * a \tag{3}$$

The vehicle contains mechanical rotary parts, such as pedals, front and rear axles, actuators, and gearbox. The equivalent mass (m_e) vehicle rises by 10–20% from the static mass of the vehicle as clarified by Eq. (4):

$$F_a = me \cdot a = (We/g)a \tag{4}$$

where m_e is measured in Kg, F_a is in N, and a is in (m/s^2).

2.3 Calculating the required force to overcome resistance of vehicle

The force which is opposed the vehicle movement is called mechanical resistance such as friction forces which existed in the axles, gears, and tires at starting. It does not depend on the speed of the vehicle and the mass of the vehicle. Wind resistance increases with the vehicle speed. Assume that F_r is the resistance force to the vehicle in (N / ton) as shown by Eq. (5).

$$F_r = m \times r \tag{5}$$

2.4 Calculating the force needed to overcome the effect of gravity

If the vehicle goes uphill at an angle θ, then the force F_g is resolved to two components and will be affected by the height axis $Sin\theta$ as expressed by Eq. (6):

$$F_g = W \times \sin(\theta) = m \times g \times \sin(\theta) \tag{6}$$

If C is the slope percentage is as expressed by Eq. (7), F_g is again identified by Eq. (8):

$$C\% = (Y/X).100 = 100 sin\theta \tag{7}$$

$$F_g = m \cdot g \cdot C \tag{8}$$

2.5 Total traction force on the tire

$$F_t = F_a + F_r + F_g \tag{9}$$

$$F_t = me \times a + m \times r + m \times C \tag{10}$$

r is measured by N/Kg. The positive sign is used when the vehicle is upward to the sloped level, while the negative sign is devoted for the vehicle downward.

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2.6 The driving power for moving the tires

If the vehicle is roaming at a constant speed V of m/s, the needed power P_o for movement is calculated by Eq. (11):

$$P_o = F_t \cdot V \tag{11}$$

If the gear efficiency is η, the needed power by electric motor P_m is calculated by Eq. (12):

$$P_m = P_o/\eta = F_t \times V/\eta \tag{12}$$

2.7 Mechanical vehicle movement

The movement of the motor spindle, which makes torque in the rotary tires, is transmitted using a gearbox to reduce the speed from N_m to N rpm, if:

The torque induced from the traction force on the tire T The traction force which drives the gears F_1.

Traction force on the tire F_t Motor speed N_m.

Wheel speed N.

Gear ratio $d_2/d_1 = \sigma$.

Diameter gear motor/diameter gear wheel stirring = $d1, d2$.

Diameter of tire (tire) D.

Gearbox efficiency η.

The relation between the motor torque T_m and traction torque required by the tire T, gear conversion ratio, and gearbox efficiency η can be simplified through Eqs. (13) to (16):

$$T_m = F_t * (d_1/2) \tag{13}$$

$$T = F_t \times (D_2/2) = \eta F_t(d2/2) \tag{14}$$

$$F_t = F_1 \eta (d_2/D) \tag{15}$$

$$F_t = F_1 \eta (d_2/D) = \eta \times 2(T_m/d_1) \times (d_2/D) = 2\eta\sigma(T_m)(D) \tag{16}$$

Ft depends on many factors: weight, wind resistance, and gradient. Furthermore, the traction force is also increased with the growing friction factor μ so that the total traction force (10) can be adjusted to Eq. (17):

$$F_t = \mu \times m_e \times a = m \times r + m \times C \tag{17}$$

3. Experimental tests and mathematical calculations

3.1 Electrical design

3.1.1 Motor and vehicle

The three-phase synchronous motor used (3PSM) is a BLDC-YG1-ZZ- 1200 W type. The choice of this motor is based on the speed and torque necessary for the load. The 3PSM is provided by an AC three-phase line voltage of 380 volt and 50 Hz. The motor maximum speed is 3000 rpm. The torque T_m of the motor can be calculated by using Eq. (18). P_o is the shaft output power. The angular velocity ω is explained by Eq. (19), where N is the speed in rpm unit [5]:

$$T_m = P_o/\omega \tag{18}$$

$$\omega = \frac{2\pi N}{60} = 314.16\,rps \tag{19}$$

where according to the real specification of the 3PSM, the torque of the motor can be calculated using Eqs. (1) and (2):

$$T_m = 1200\,W/(2 \times 3.14 \times 3000/60) = 3.8\,n \cdot m$$

This anticipated torque is significantly adequate with 3000 rpm for the present load and as an input of mechanical gearbox. The next qualifications of the mechanical gear box will depend firmly upon the two manufactured torques: torque of the 3PSM and traction torque required for the vehicle load. **Figure 2** shows the three-phase synchronous motor which is used for vehicle and its nameplate.

3.1.2 Gearbox and vehicle load

The gearbox used in the vehicle is shown in **Figure 3**. It is subjected to many factors: input and output speeds and input and output torques required. The present vehicle has a steady-state linear speed which reaches slightly more than 40 km/hr. The angular velocity of vehicle tires is explained by Eq. (20), where r is identified as the tire radius. The real tire radius is measured to give 0.125 m. The angular speed of gearbox pulley is determined by Eq. (21):

$$V_t = 2\pi r\,\omega_t \tag{20}$$

$$\omega_t D = \omega_2 d_2 \tag{21}$$

where according to the real linear speed of the vehicle' tires, the angular speed of the tire can be calculated using Eq. (3):

$$40000/(60 \times 60) = 2\pi \times 0.135 \times \omega_t$$
$$\omega_t = 13.1\,rps$$

Then, the rotation speed the gearbox output pulley ω_2 is calculated using Eq. (4):

$$13.1 \times 0.27 = 0.04\,\omega_2$$
$$\omega_2 = 88.425\,rps$$

Figure 2.
Three-phase synchronous motor for vehicle traction and its nameplate.

3.1.3 DC/AC inverter

The DC to three-phase inverter is designed as a frequency changer [6]. The synchronous speed of the 3PSM is various using the frequency changer and is determined by Eq. (22):

$$N_s = 120f/p \tag{22}$$

where from the experimental tests of the 3PSM conditions, the real number of stator slots is designed to give 18 slots. The stator has three phases, and six coils/phases are determined; for the motor shaft speed of 3000 rpm, it means that there are three coils per one pole inside the motor stator. Then, by using Eq. (22) and the obtainable data, the range of input frequency f can be calculated:

$$3000 = 120f/6$$

Then the frequency f of 300 Hz represents the maximum frequency necessary required from the three-phase inverter to the 3PSM. This frequency leads the vehicle and reaches to a maximum linear speed of 40 km/h.

The real inverter designed is explained by **Figure 4**.

3.1.4 Batteries

Five series batteries are connected; each battery is a 12 VDC and 14 AH lead-acid sealed type. The entire voltage is 60 VDC which is supplied to the terminal inputs of the inverter. **Figure 5** highlights the used battery.

Figure 3.
Motor gearbox.

Figure 4.
The DC to three-phase voltage inverter used.

Figure 5.
The used battery of 12VDC and 14 amp.hr.

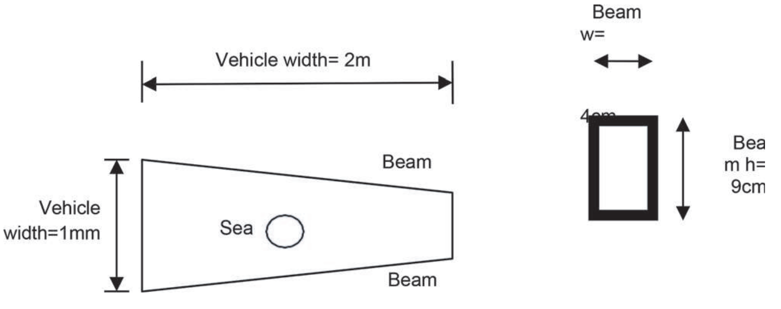

Figure 6.
Dimensions of the vehicle iron beams 1 and 2.

3.2 Mechanical design

3.2.1 Binding stress calculations τ_b

The main supports and joints used for the vehicle frame are iron hollow rectangular metal beams with dimensions of 1.5 inch and thickness of 2 mm. The length of the iron beams 1 and 2 is the same; each beam length is 2 m. **Figure 6** shows the lengths of the vehicle structure iron beams 1 and 2.

The bending stress is determined at the center of beam 1 and beam 2. The total weight of the driver, five batteries, and solar panel are checked to give a weight of 125 kg. The gravitation force downward by total weight is calculated using Eq. (23):

$$F_\omega = m_\omega \times a_g \tag{23}$$

$$F_\omega = 125 \times 9.8 = 1225N$$

The bending stress will be determined using Eq. (24):

$$\tau_b = F_b / A_b \tag{24}$$

The bending force is distributed into beams 1 and 2 at the middle of each, so the force F_w must be divided by 4. The length of beams is 2 m as shown in **Figure 6**, and the rectangular dimension length of cross-sectional area of beams 1 and 2 is 9 cm $\times$ 4 cm, and its thickness is 1.5 mm. The τ_b calculation is implemented using Eq. (24) [3]:

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Figure 7.
Solar panel is supplying power to the batteries.

$$\tau_b = \frac{(F_b/4)}{(2(h+\omega)\times t)} = \frac{(1225/4)}{(2(0.09+0.04)\times 0.015)}$$
$$= 78.5\frac{N}{m^2} << \text{Bending stress of mild iron } 360\frac{MN}{m^2}$$

where A_b is the cross-sectional area of hollow rectangular beams 1 and 2 at the tires' shafts.

3.2.2 Axial shear stress calculations of each tire τs

The total axial force F_s (similar to F_w) is composed by the driver, five batteries, and the iron frame weights which it is concentrated onto three tires (two rear tires and one in front). The entire force F_s should be divided by three tires and two rod sides per tire. The three circular iron solid rods have each 1 centimeter diameter. The axial shear stress τ_s can be determined using Eq. (25):

$$\tau_s = F_s/A_s \tag{25}$$

$$\tau_s = F_s/(3tires \times 2sides \times A_r) = (1225)/(3*2*3.14*(0.01)2/4)*0.015)$$
$$= 2.6MN/m^2[1] << \text{shear stress of mild iron } 36MN/m^2.$$

3.2.3 Pedal and gears

Two gear discs are used to transfer the mechanical power created by legs for turning the tires and then the vehicle. It is instituted experimentally; the torque established T_d by the legs is sufficient to move vehicle which is closed to bicycle. To calculate the torque established T_d, can be applied by (13) on the pedal and tire system.

$$T_d = 125kg \times 9.8N/m^2 \times (0.27/2) = 165.375N\cdot m,$$

The minimum mechanical torque required to move the vehicle which is less than the torque required for moving the bicycle with the driver is equal to 85 kg × 9.8 N/m^2 × (1/2) = 415 $N \cdot m$.

3.2.4 Solar design

The solar panel (type SK150D, 150 watts, 18 V, 8.33 Amp) used is considered as additional power source and has the following specifications as shown in **Figure 7** through its nameplate. The rated power produced is amplified by using power electronic chopper (low DCV/high DCV) to convert the low-DC volt input to the required volt which is 60 DCV. The solar panel is used for charging the five batteries under the sunlight.

4. Results and discussion

The investigational tests on the electric motor of the vehicle are shown for the three different speeds, the AC line-to-line voltages are measured, and instantly the current is drawn by the electric lines. The investigational tests are revealed in **Table 2**.

Based on these experimental tests, the power input and output of the 3PSM can be calculated using the following performance equations for the 3PSM [3]:

$$P_{in} = 1.73 V_L I_L \cos\theta \tag{26}$$

$$P_{mo} = T_{sh}\,\omega = \eta_m P_{in} \tag{27}$$

The results of test 1 are shown in **Table 2**. By using Eq. (26), the power factor can be supposed as 0.8 [5, 7]:

$$P_{in} = 1.73 \times 36 \times 5.13 \times 0.8 = 255.6\,W$$

Referring to test 2, P_{in} = 363.6 W. Pin = 456.72 W for test 3.

Then, efficiency of the 3PSM can be supposed as 0.9 [5, 7]. By reusing Eqs. (20), (21), and (27), the torque induced is:

$$0.9 \times 456.72 = 2\pi \times (1500/60) \times T_{sh}$$

T_{sh} = 2.6 N.m is produced by the motor initially to increase it through the gearbox. Finally the required torque is achieved for moving the vehicle.

Test no.	Vehicle speed (km/hr)	3PSM line-to-line voltage (volt)	3PSM line current (ampere)
1	20	36	5.13
2	30	47	5.59
3	40	55	6

Table 2.
Experimental tests.

5. Conclusion

The investigational tests and theoretical calculations of the vehicle show that there is a good confirming result which satisfied the required torque and speed. There is some enhancement that needs to be applied in the future to reduce the iron size of the two beams by using a smaller size. Furthermore to that, it is possible to use four tires instead of three tires. Also electronic control devices can be advanced by using Arduino controller applications.

Author details

Khalid G. Mohammed
Scientific Affairs Department, University of Diyala, Iraq

*Address all correspondence to: khalid_alkaisee2013@yahoo.com;
khalid_alkaisee@engineering.uodiyala.edu.iq

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